



Radiation Damage and Recovery in Solid Polarized Targets

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Univ. of Virginia Polarized Target Group
Polarized Drell-Yan Workshop, Santa Fe NM, 11.1.2010



Outline

- Dynamic Nuclear Polarization
- Target Material Preparation
- Material Use
 - Beam Heating
 - Radiation Damage
 - Polarization Decay
 - Material Lifetime
 - Radiation Recovery: Anneals
- Recent Examples from Jefferson Lab:
 - SANE
 - egl-dvcs

Dynamic Nuclear Polarization

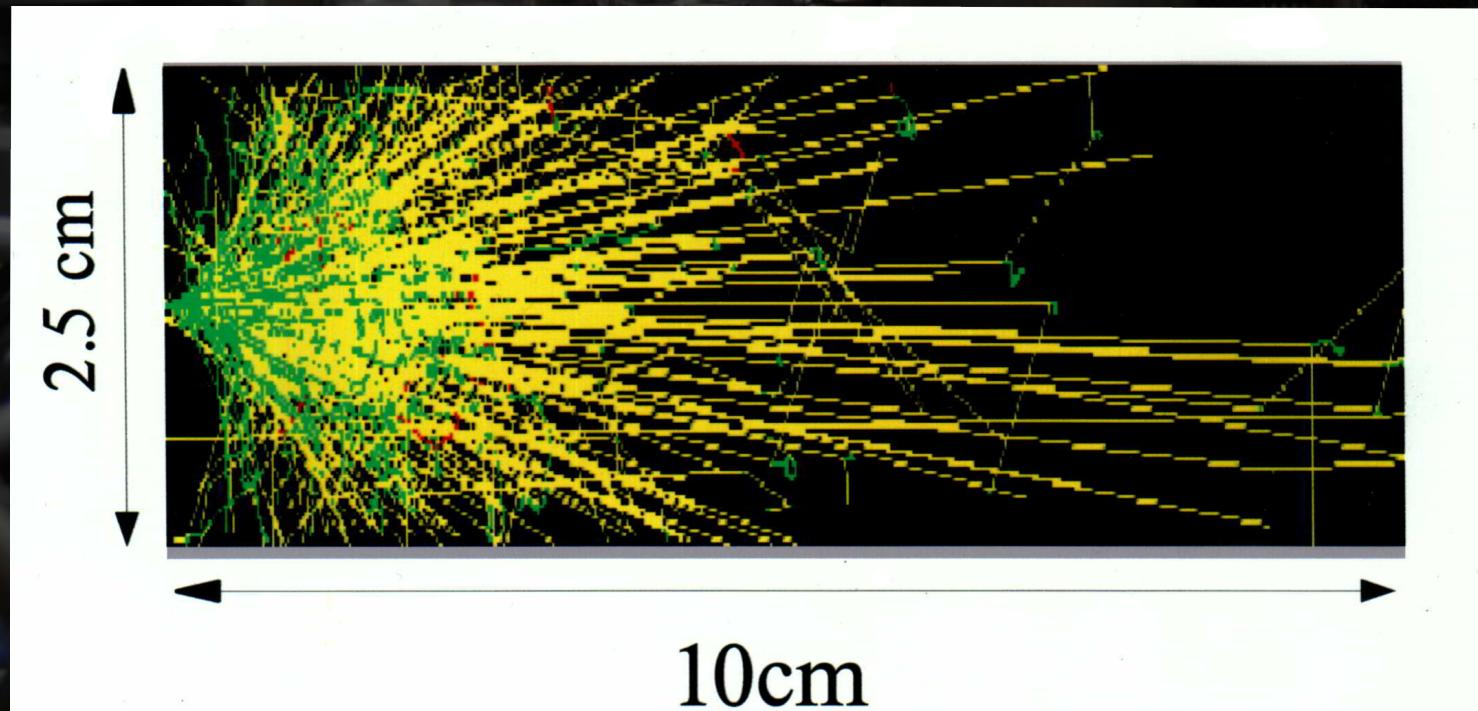
- Leverages paramagnetic radicals which provide electron-proton hyperfine splitting in a high magnetic field, at 1K
- Microwaves drive transitions to populate levels
 - Electron relaxation time ~milliseconds
 - Proton relaxation time ~10s of minutes
- Extra electrons for this coupling provided by doping material with paramagnetic radicals
 - Chemical dopant: EHBA-Cr(V), TEMPO
 - Radiation doping: Butanol, Ammonia, LiH, also deuterated
- Choose material based on dilution factor, polarizability (rate and value), radiation resistance, other polarizable nuclei

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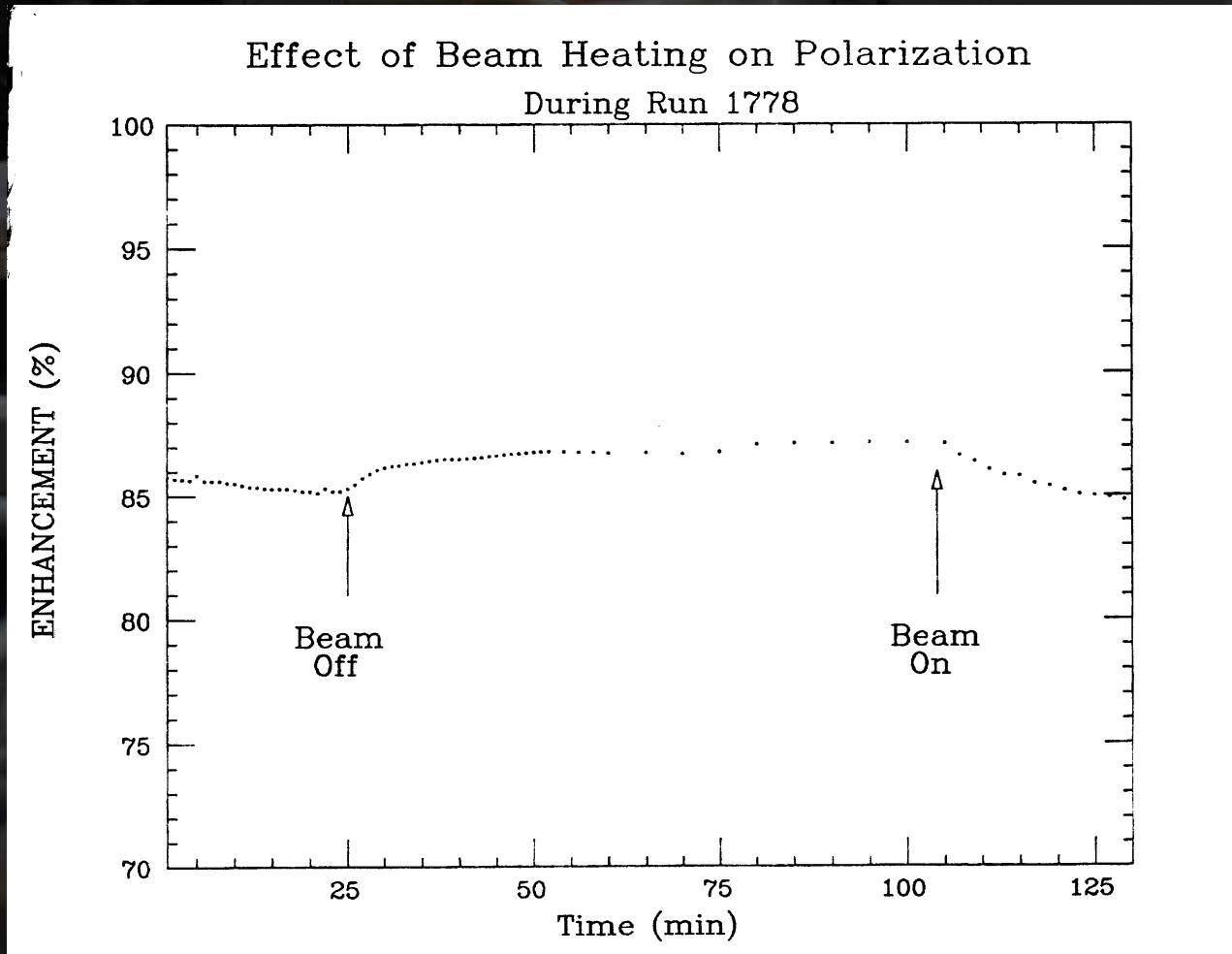
Irradiation Doping

- Create paramagnetic radicals with high-intensity, ionizing beam
- In case of our NH_3 MIRF accelerator NIST, Gaithersburg, MD
 - Irradiation dose $\sim 10^{17} \text{ e}^-/\text{cm}^2$ at 19 MeV, under 87K Ar
 - After “warm” dose, achieve $>90\%$ polarization in NH_3



Experimental Beam on Target: Beam Heating

- The first effect of the beam is a reduction of DNP efficiency simply due to heating. For 90% proton, this means ~5% loss.

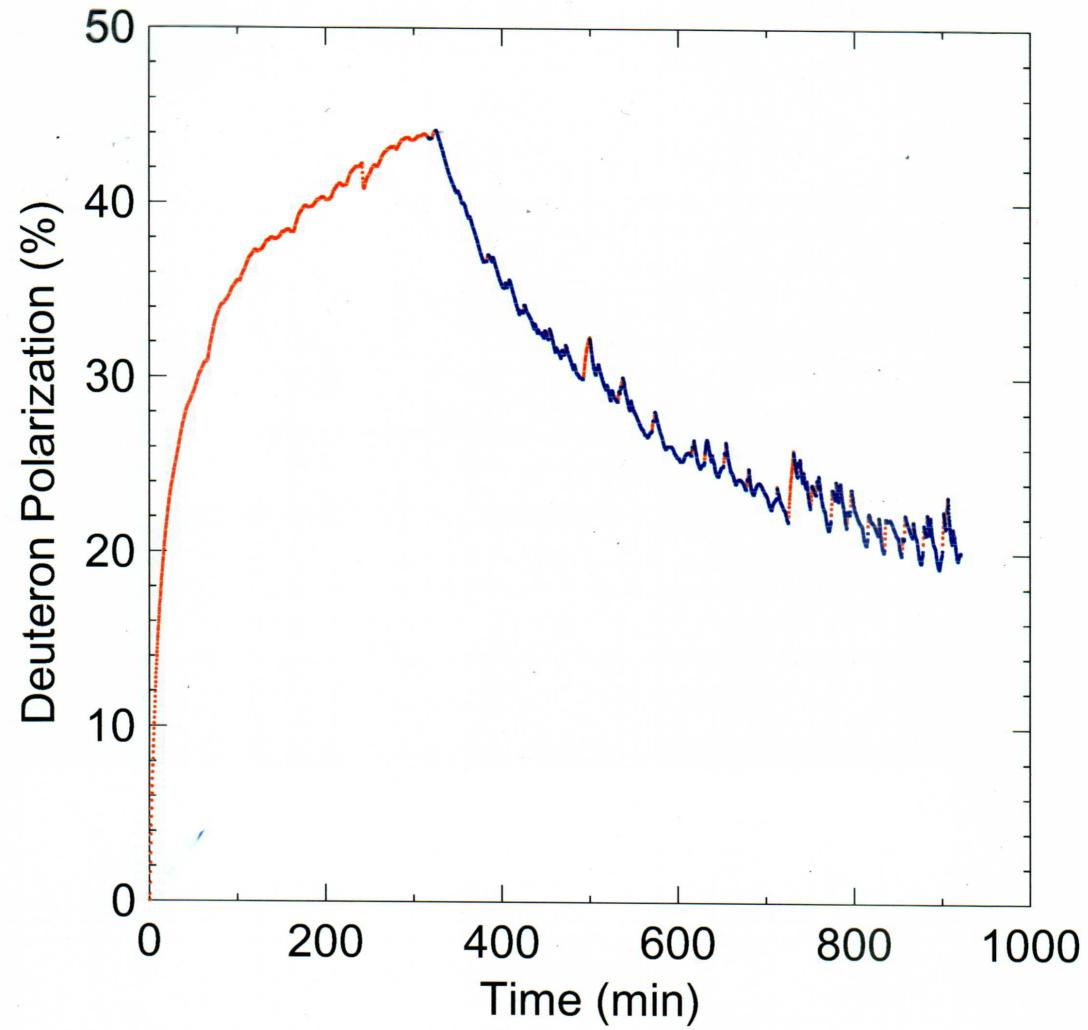


Brookhaven: 1989

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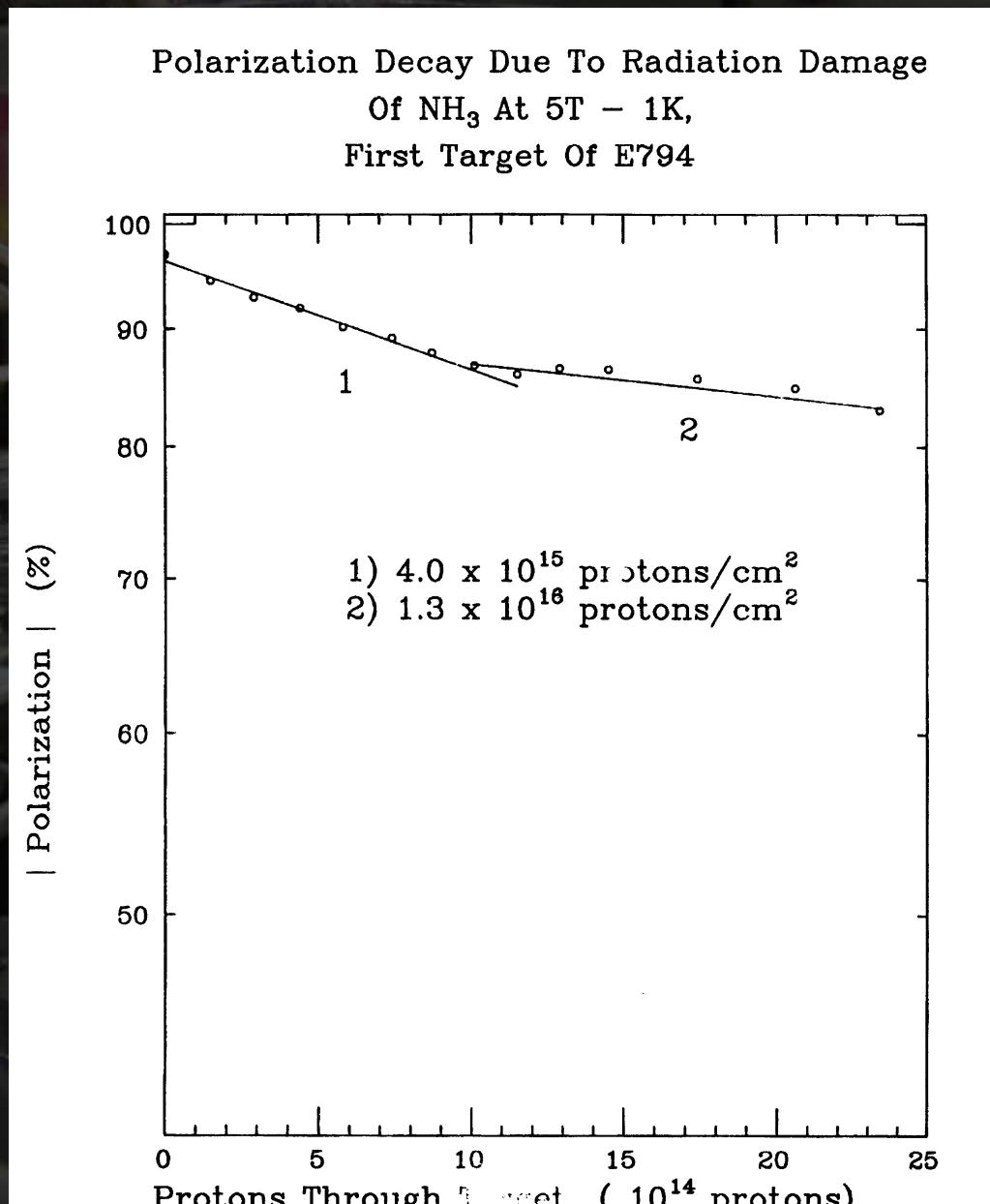
Beam Heating: $^{15}\text{ND}_3$

Gen Target Performance, 10Sep01



Polarization Decay in Experimental Beam

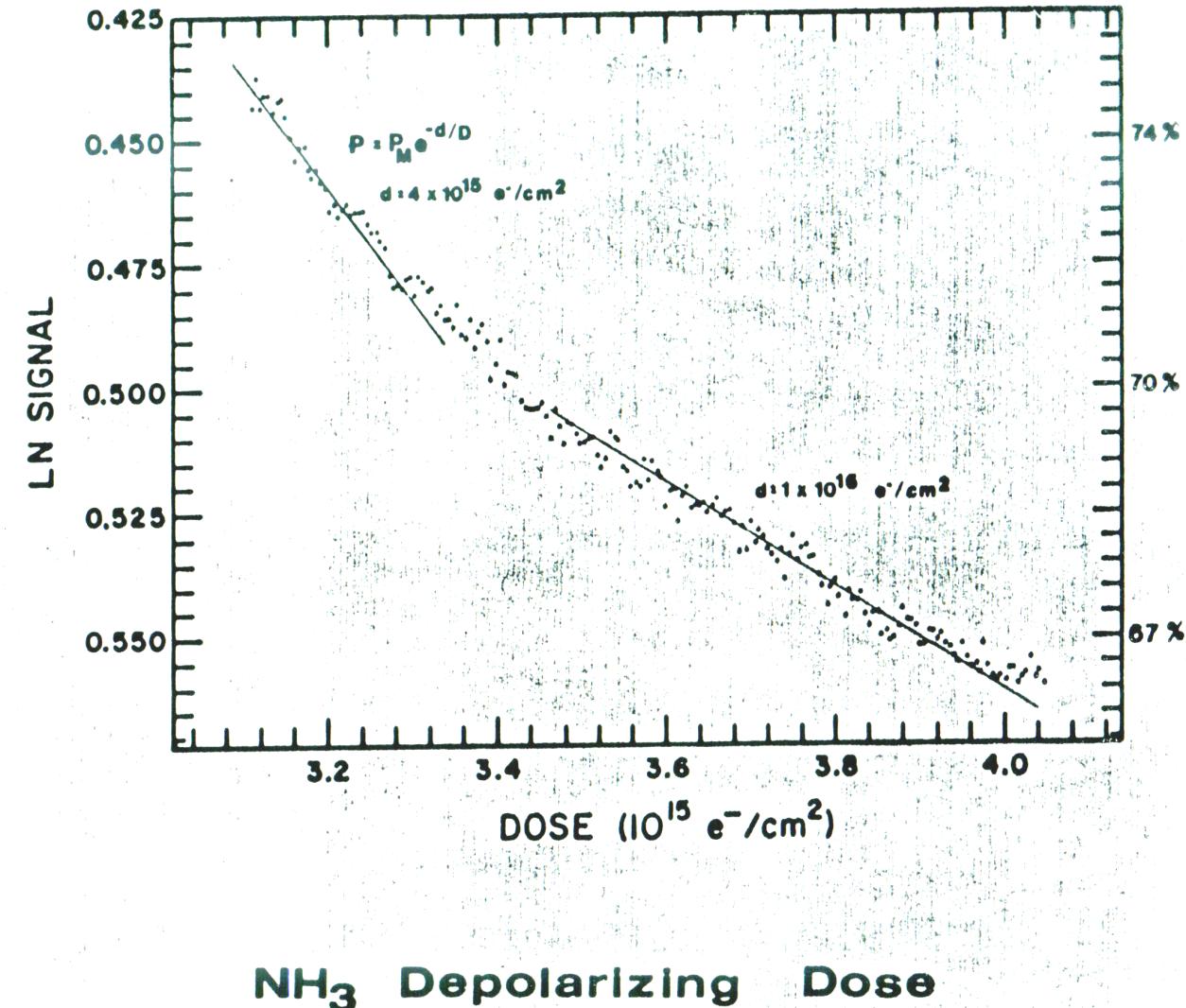
- In target application, radiation dose causes decay in polarization
- Build up of excess and unwanted radicals under this “cold” dose creates more decay paths for depolarization
- 2 exponentials present in the decay as different types of radicals build up



Brookhaven: 1989

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Polarization Decay in Beam

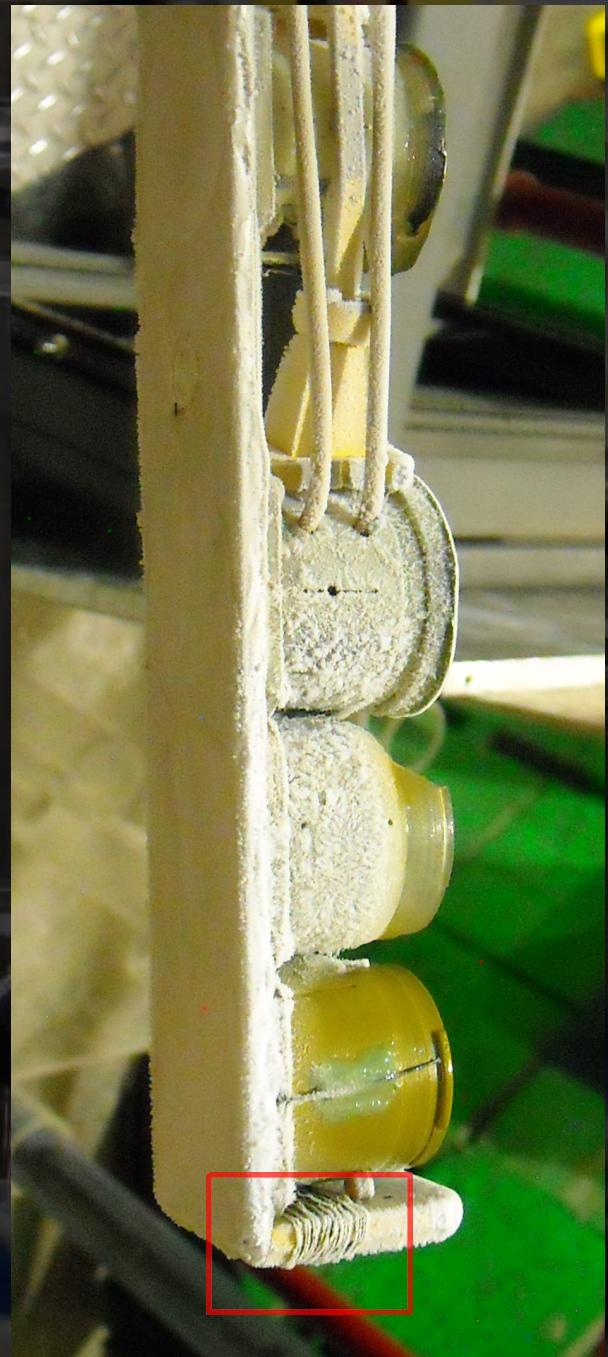


SLAC: Seely, 1982

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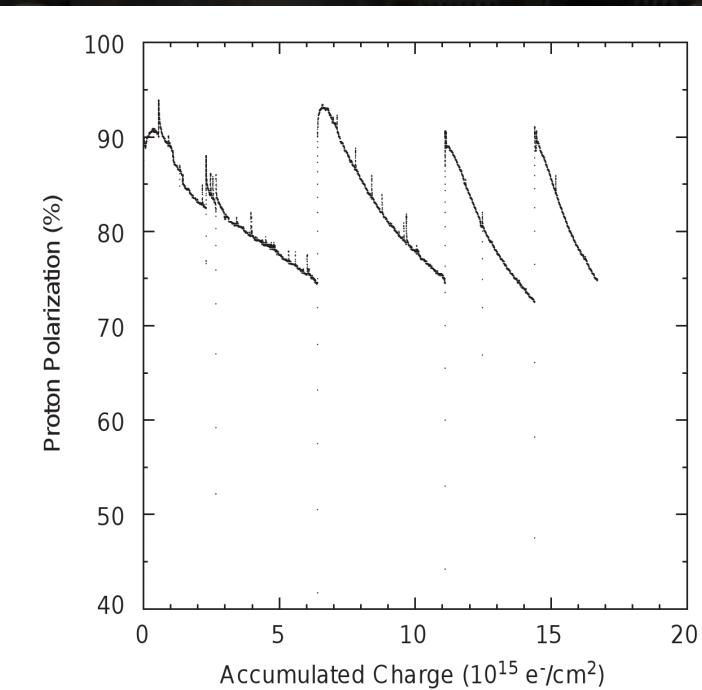
Radiation Damage Recovery

- To regain polarization lost to radiation dose: Anneals
- Heat material to allow excess and unwanted radicals to recombine
- Current through wire heats helium as it passes through perforated ladder
- Raise to 70-100K for 10-60 minutes
- For $^{14}\text{NH}_3$, necessary after $\sim 2\text{-}4 \text{ Pe}^-/\text{cm}^2$
 - At 100 nA, this is ~ 8 hours
 - Daily for 2 cup target loads
 - At 7 nA, this is ~ 110 hours
 - Nearly 2 weeks for 2 cup loads



Radiation Damage: End of Life

- There is still a limit to material lifetime
- As more dose is accumulated after successive anneals, the rate of polarization decay in beam increases
 - Not all radicals can be removed during anneals
- Polarization will eventually decay so quickly in beam, that more anneals are necessary than is practical and material should be replaced
 - In $^{14}\text{NH}_3$, this occurs after 20-30 Pe^-/cm^2



Polarized Ammonia Target Experiments in 2009

Hall C: SANE

- Inclusive, double polarization
- Spin asymmetry A_1 , spin structure function g_2
- Higher twist, quark-gluon correlations
- $2.5 \leq Q^2 \leq 6.5 \text{ GeV}^2$,
 $0.3 \leq x_{\text{Bj}} \leq 0.8$
- “U.Va.” $^{14}\text{NH}_3$ DNP Target:
 - 5T at 90° - 180° to beam
 - Polarization $>70\%$ at beam current $\sim 100\text{nA}$, 1K

Hall B: EG1-DVCS

- GPD study via Deeply Virtual Compton
- CEBAF Large Acceptance Spectrometer: CLAS
- Single and double spin asymmetry simul.
- $Q^2 \leq 1 \text{ GeV}^2$
- “Hall B” $^{14}\text{NH}_3$ DNP Target:
 - 5T at 180° to beam
 - Polarization $>70\%$ at current $\sim 7\text{nA}$, 1.2K

Polarized Ammonia Target Experiments in 2009

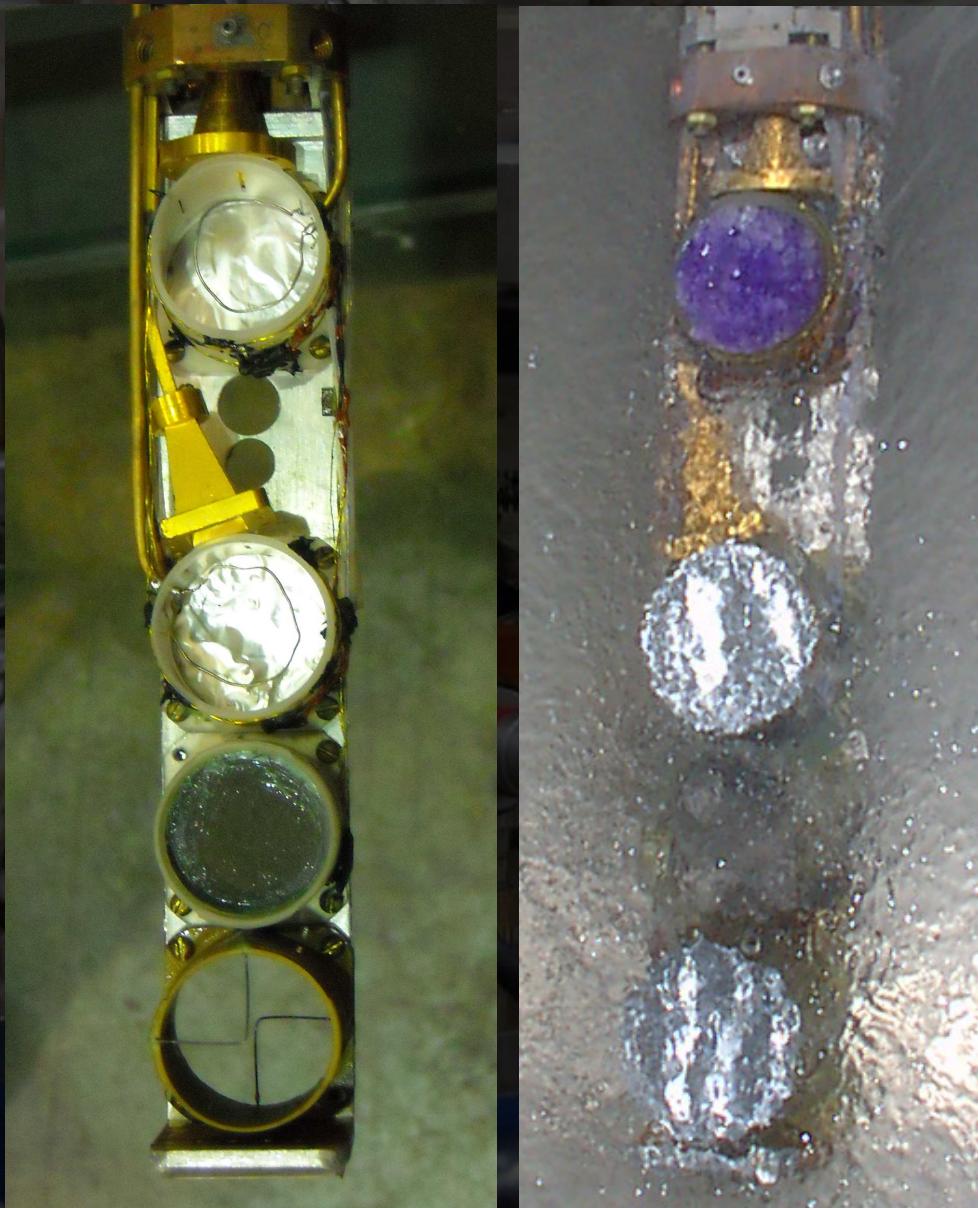
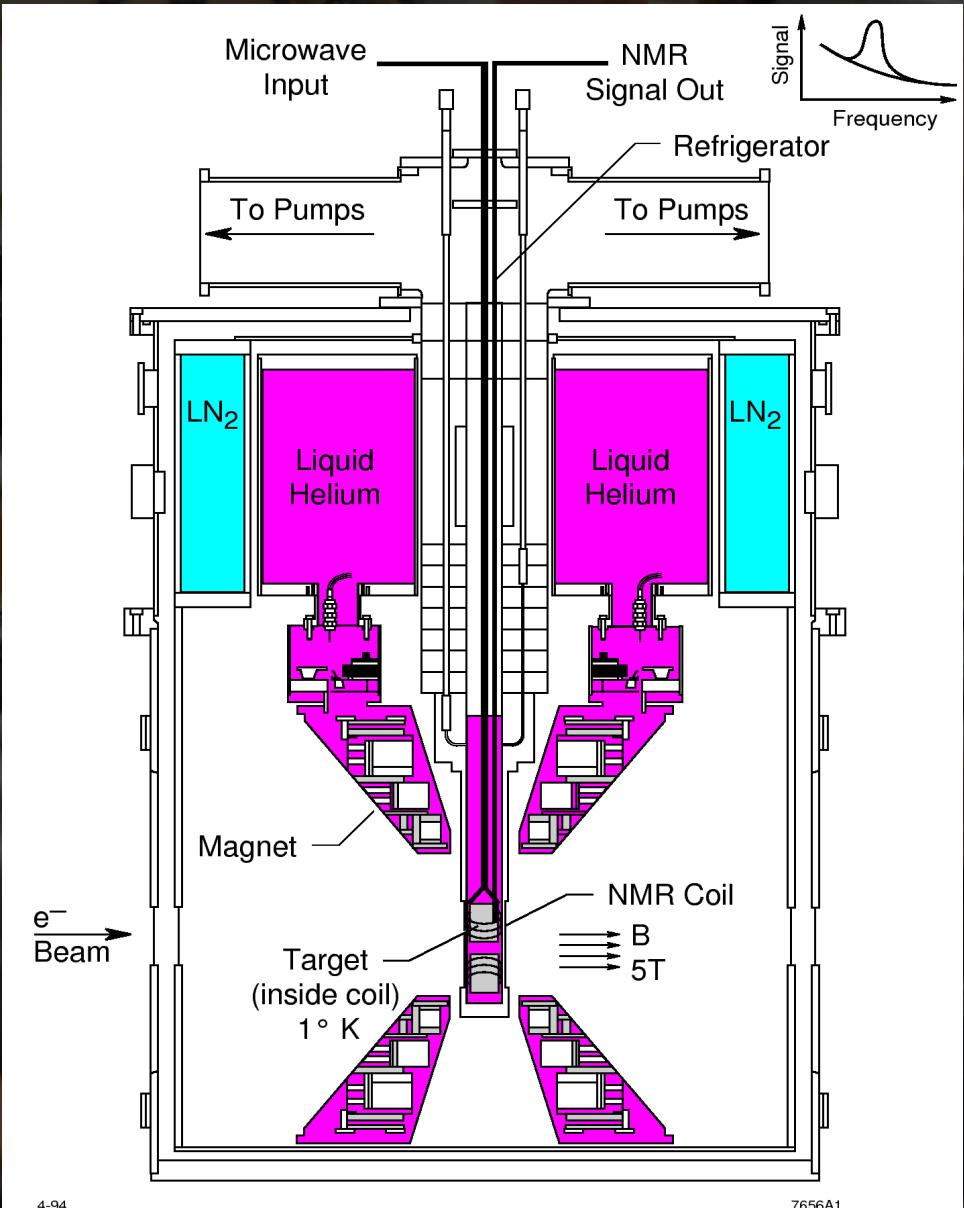
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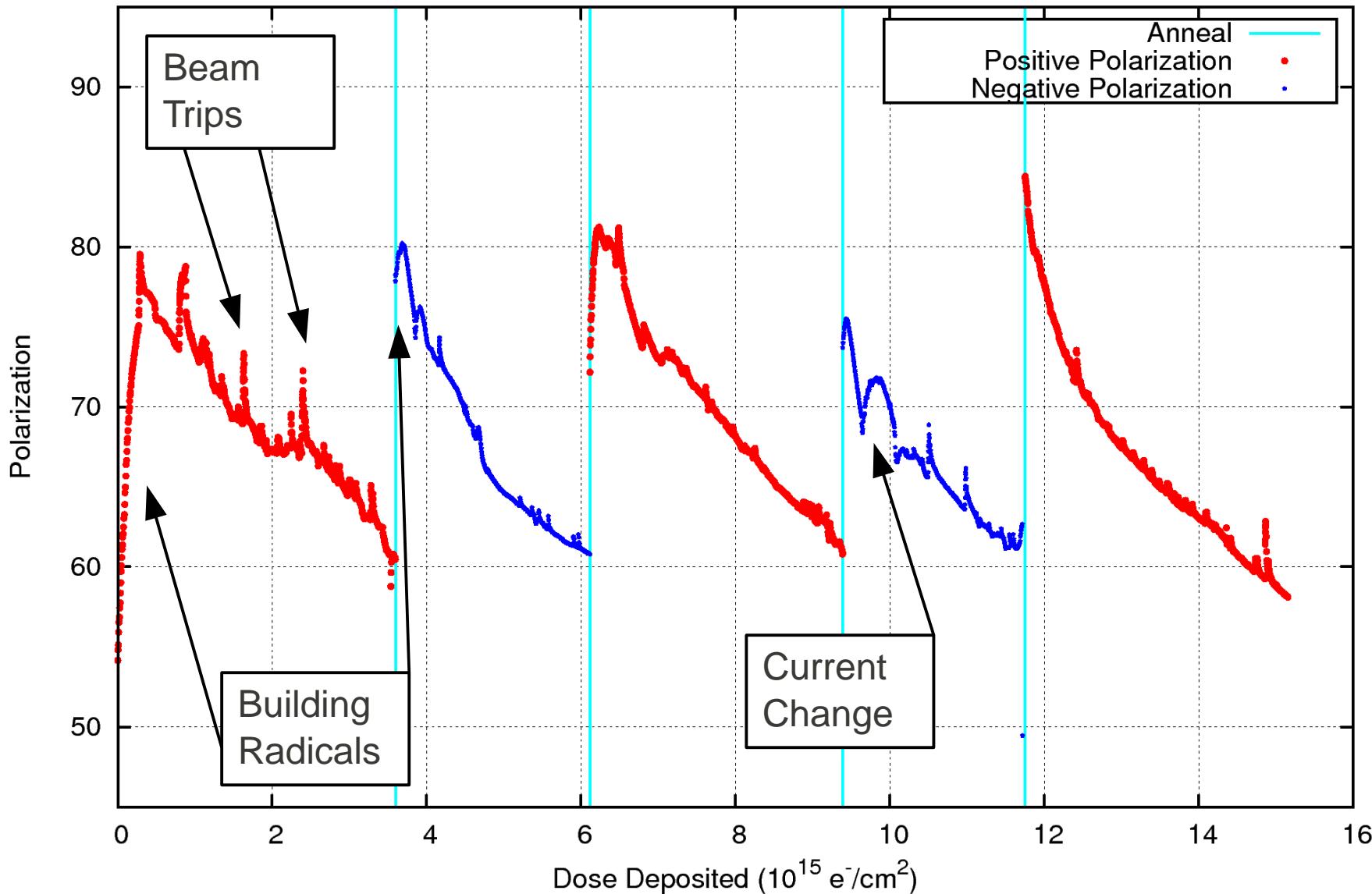
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UVa Polarized Target



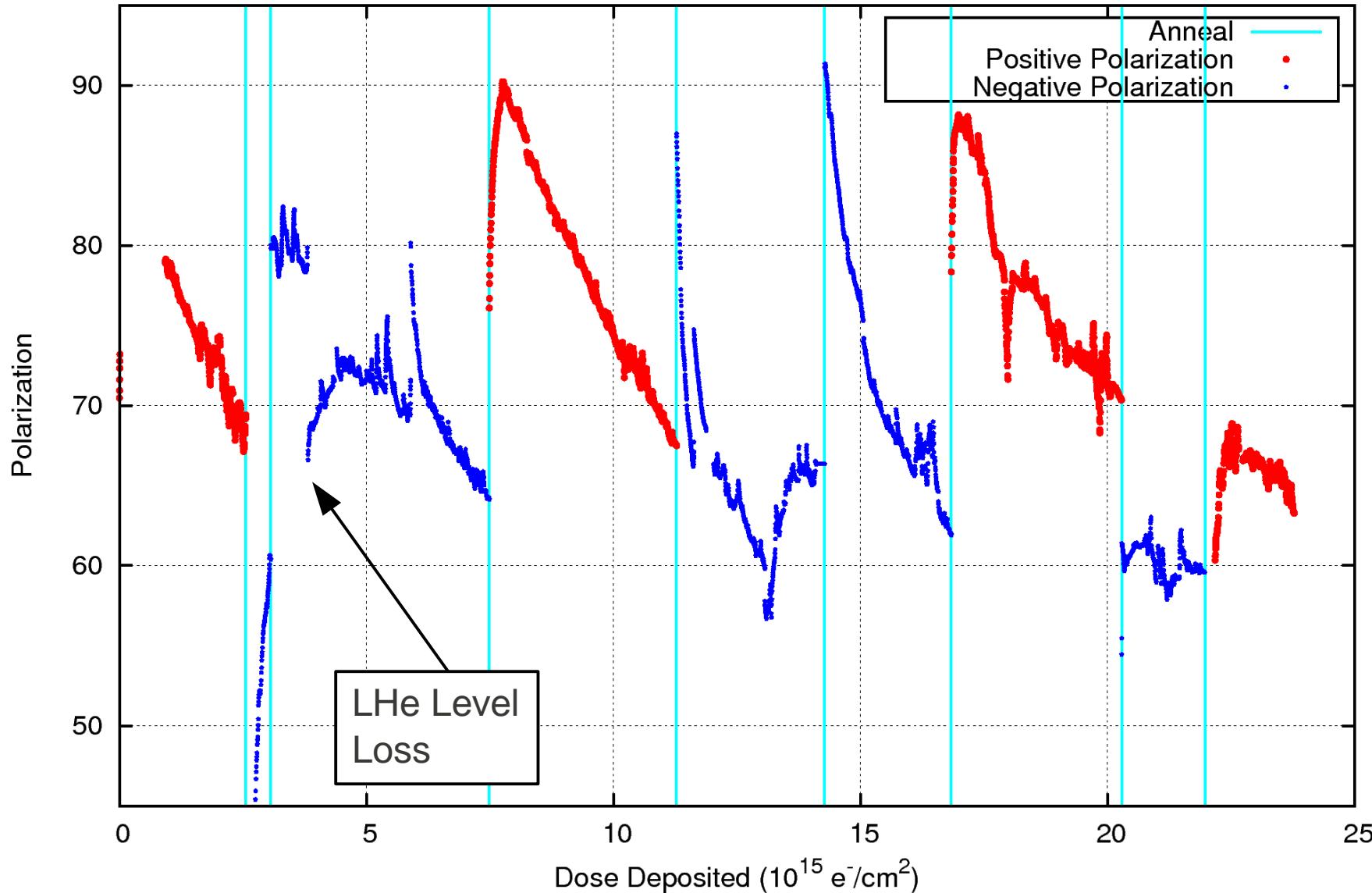
SANE: Polarization Decay with Dose

Polarization vs Dose on Material Start Run 72986



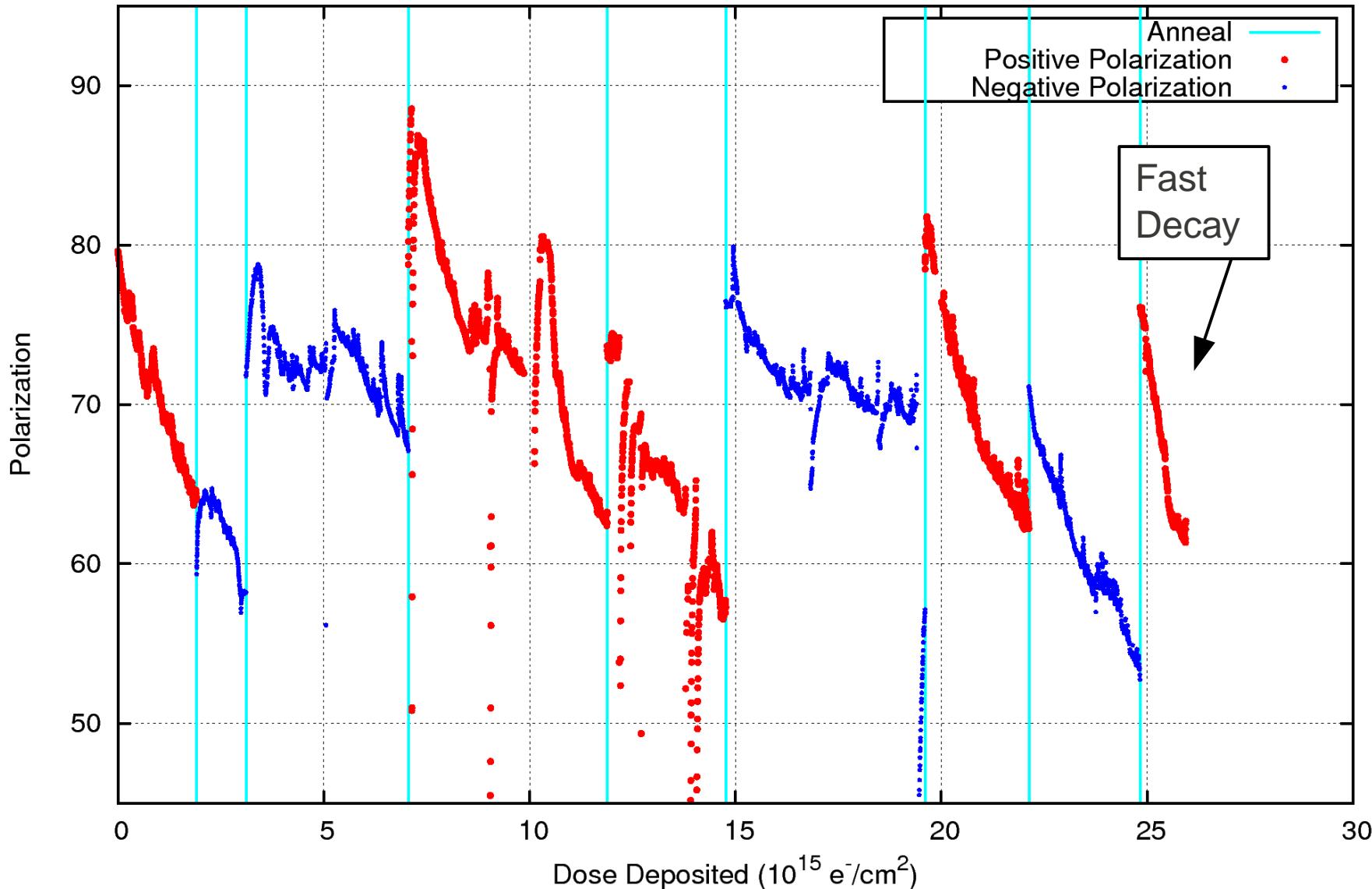
SANE: Polarization Decay with Dose

Polarization vs Dose on Material Start Run 72417

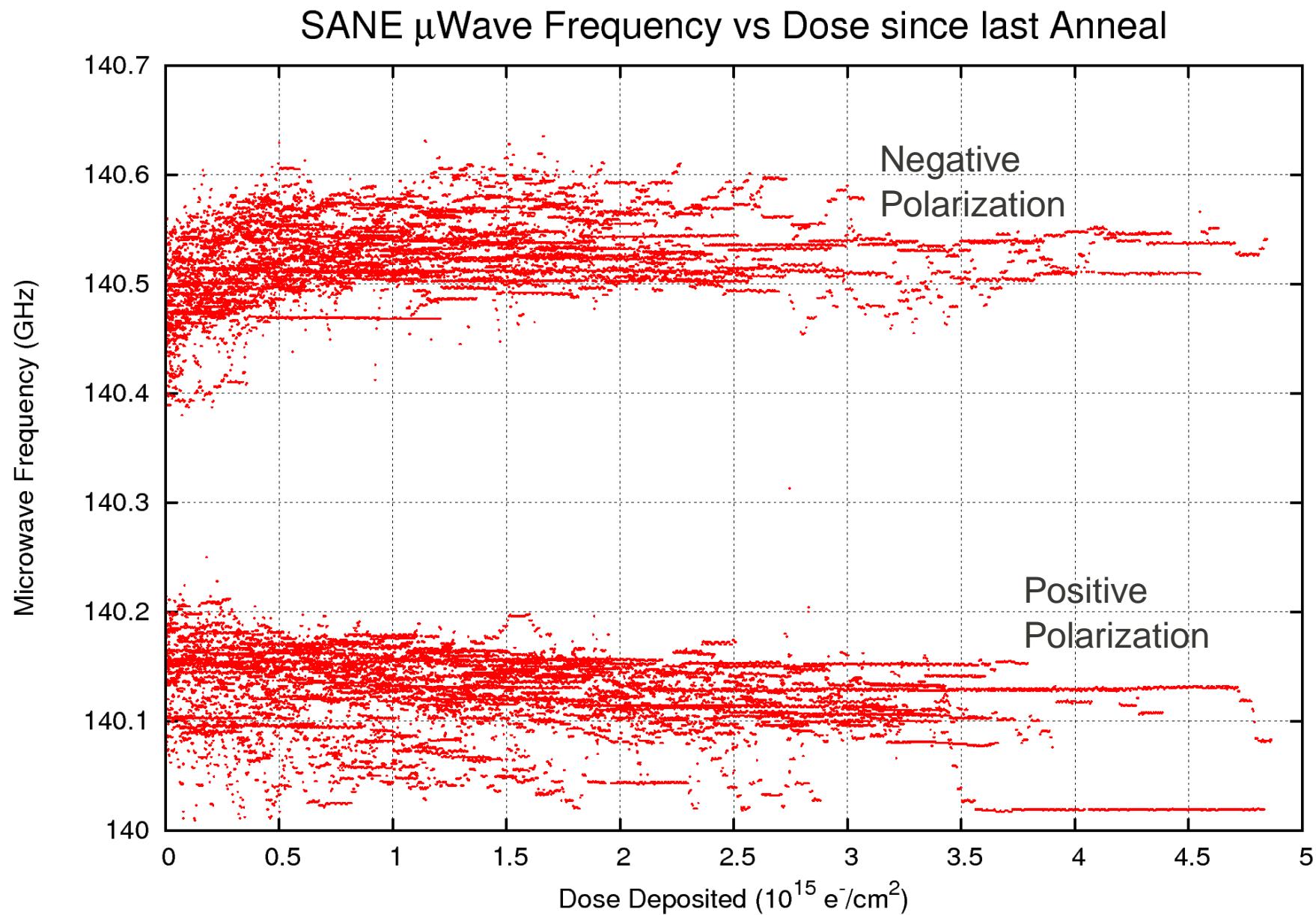


SANE: Polarization Decay with Dose

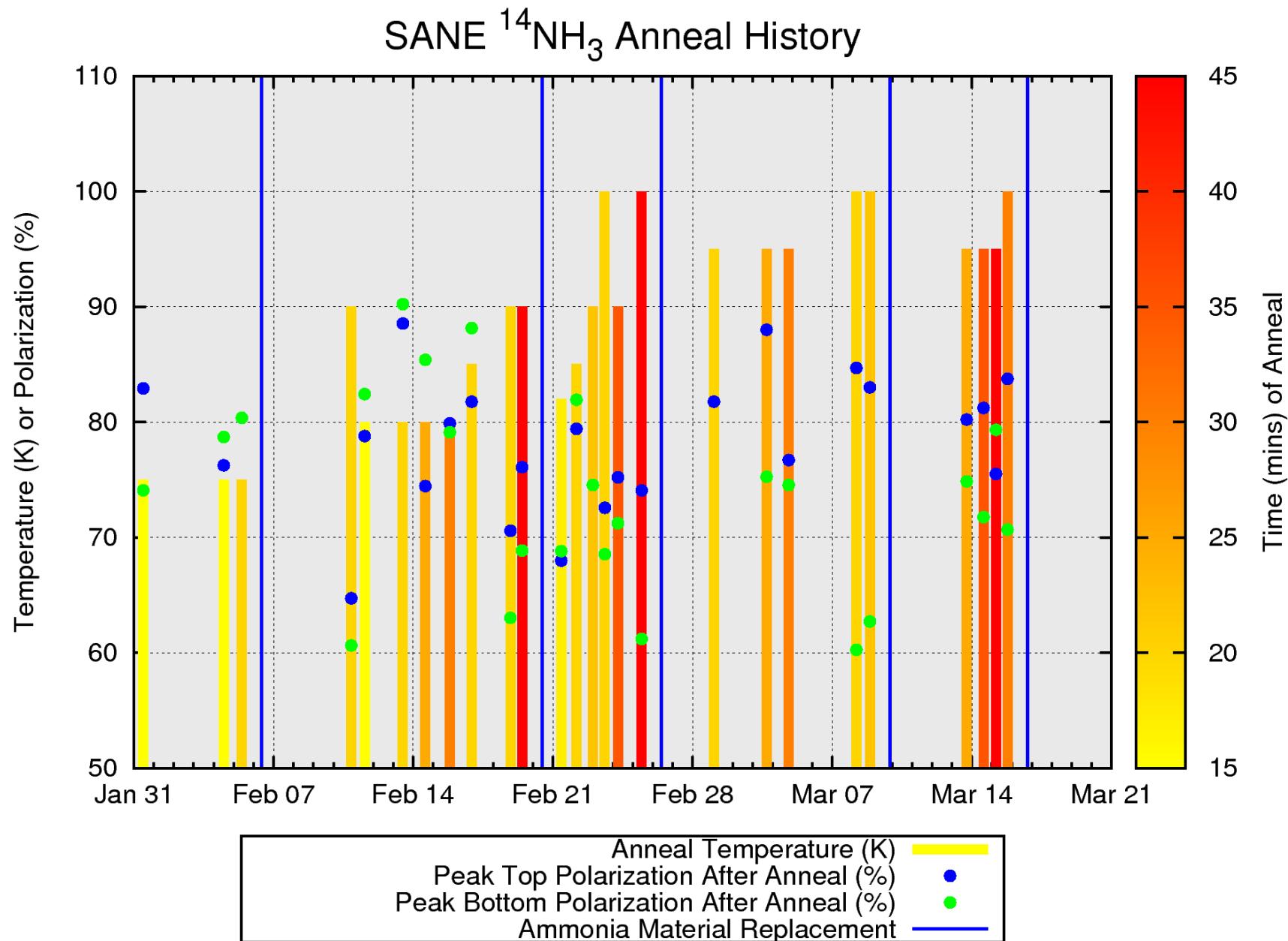
Polarization vs Dose on Material Start Run 72428



SANE: “Optimal” Microwave Frequency vs. Dose

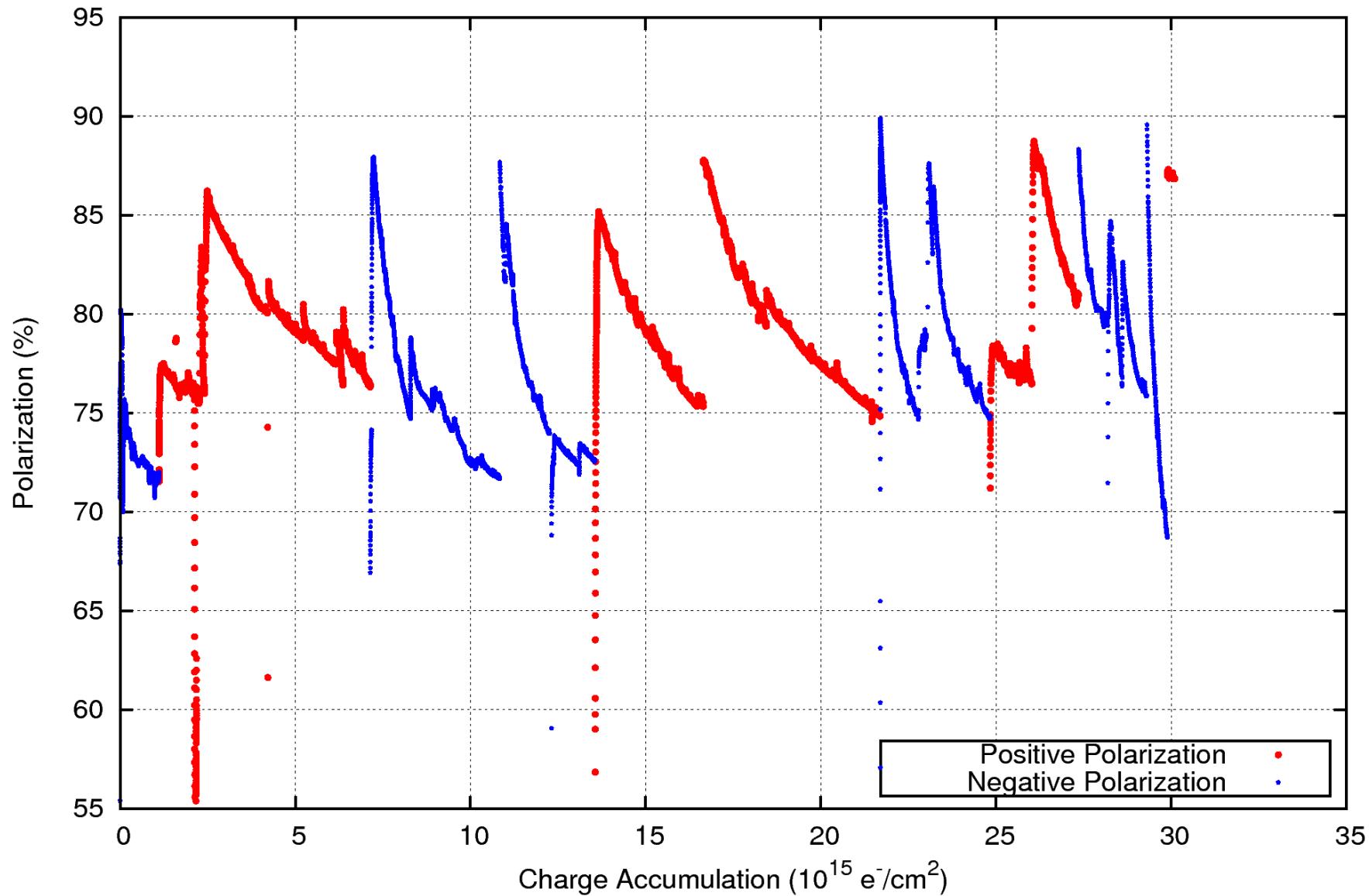


SANE: Anneal History

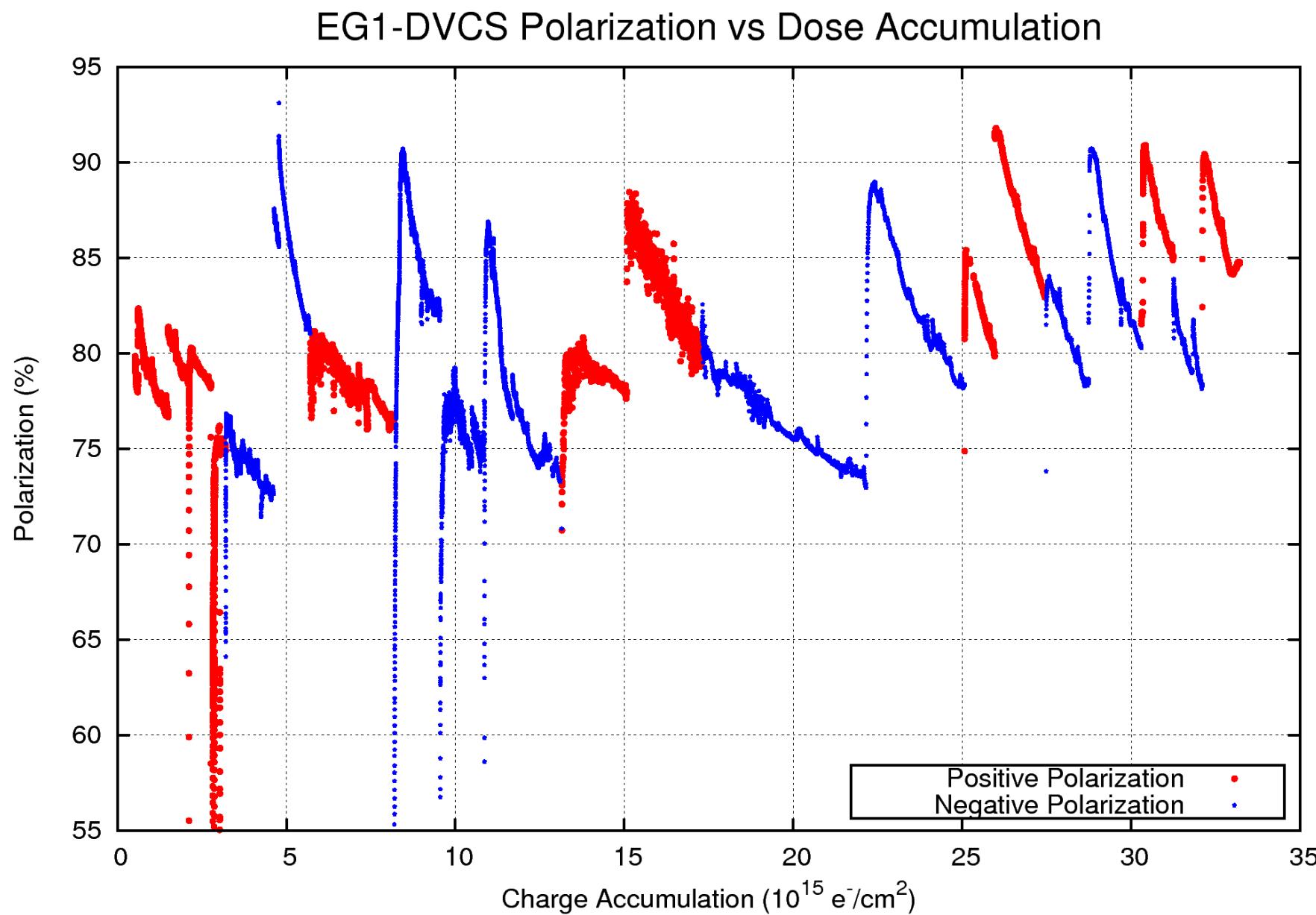


EG1-DVCS: Polarization Decay with Dose, Top

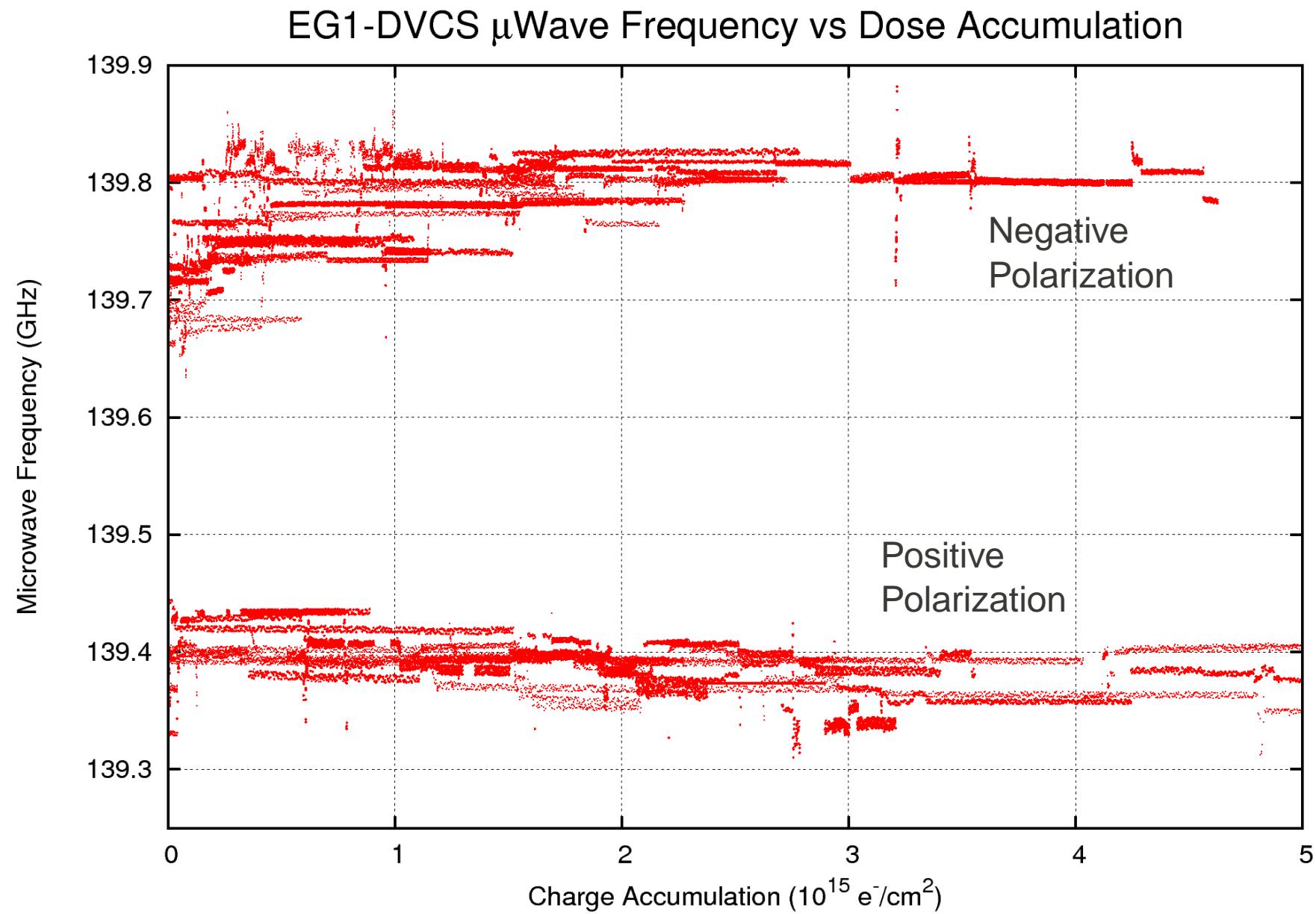
EG1-DVCS Polarization vs Dose Accumulation



EG1-DVCS: Polarization Decay with Dose, Bottom

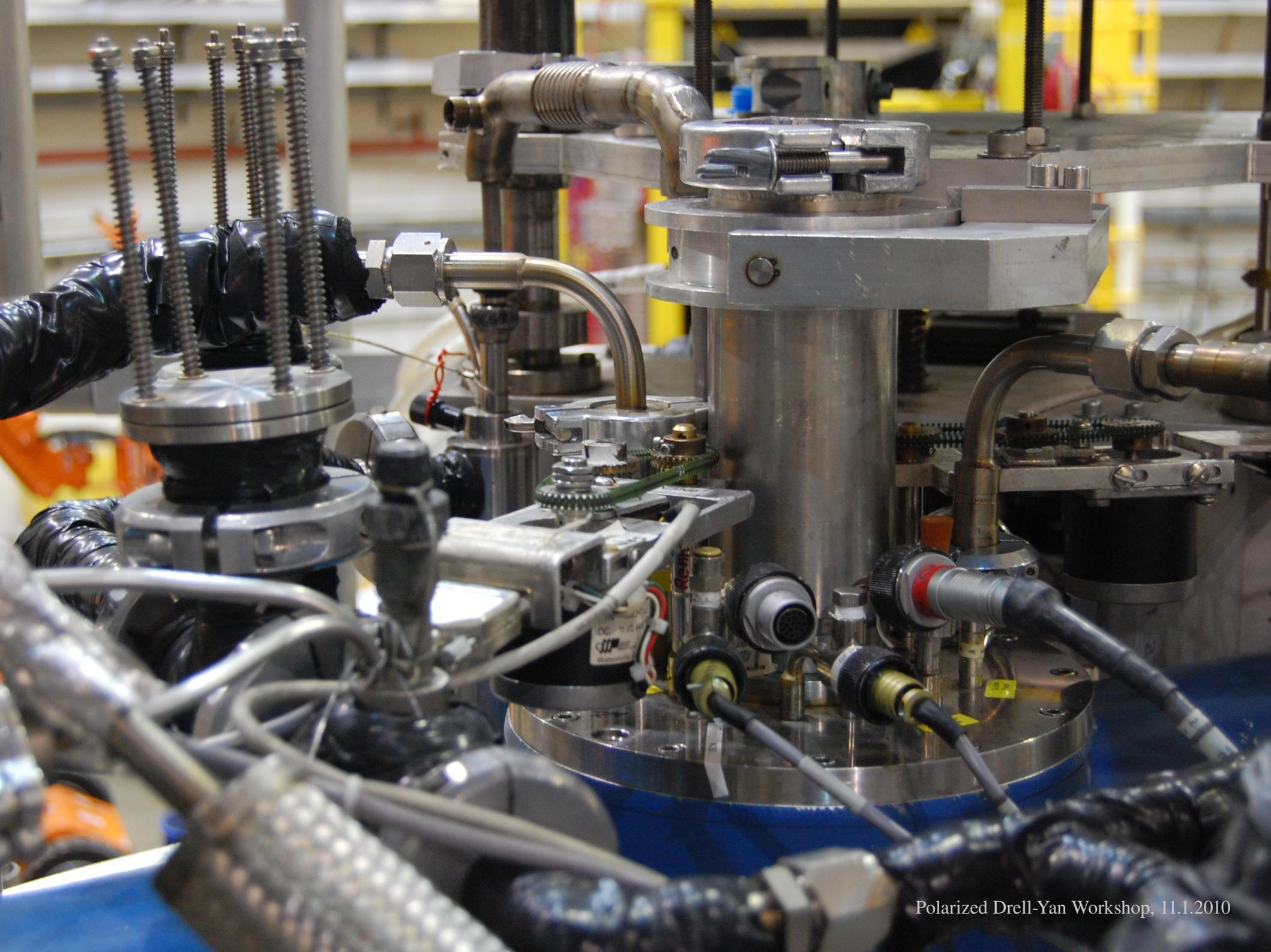


EG1-DVCS: “Optimal” Microwave Freq vs. Dose



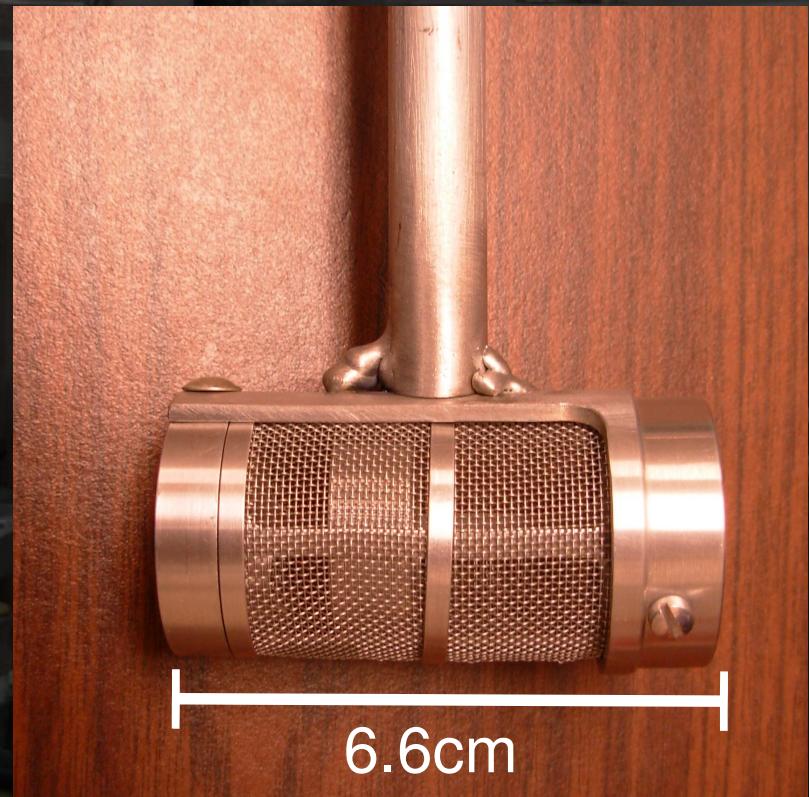
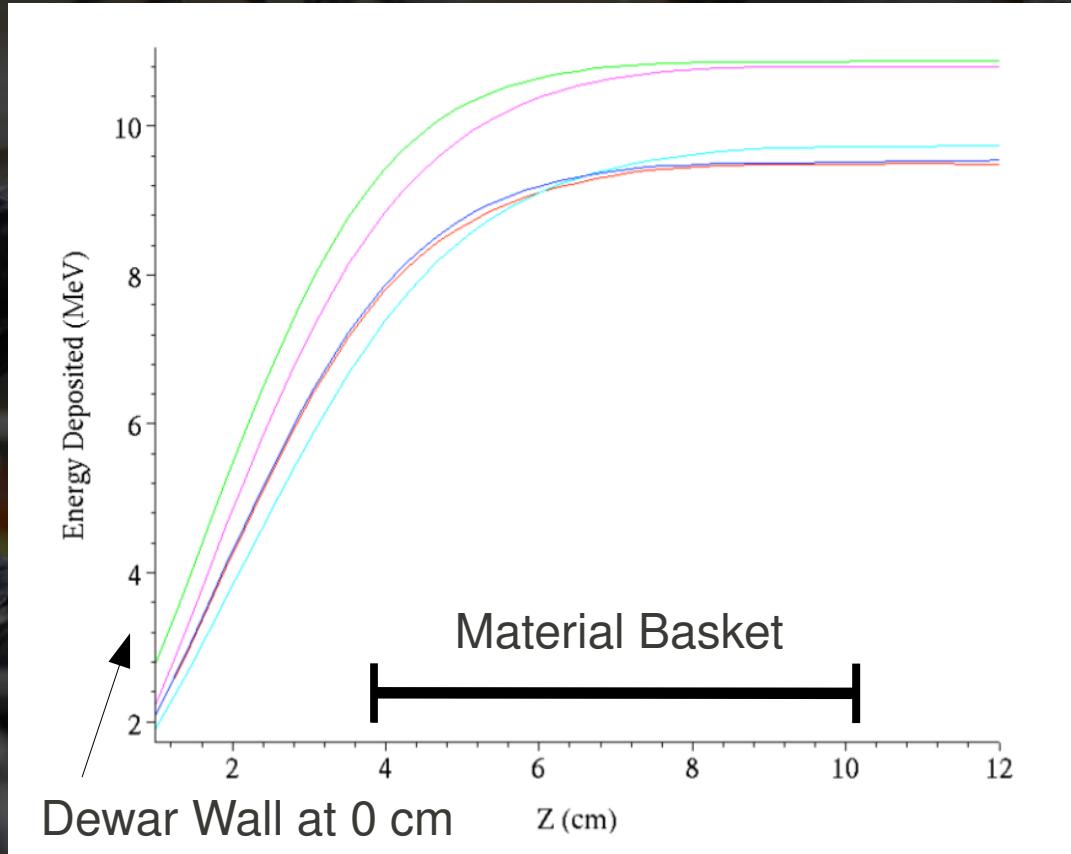
Summary

- General impression of target behavior in experimental situations
 - Irradiation doping
 - Beam heating
 - Depolarization under radiation damage
 - Polarization recovery in anneals
- Shown examples of solid polarized target use over the course of the past 30 years under diverse conditions:
 - Brookhaven's proton beam
 - SLAC's pulsed electron beam
 - CEBAF's continuous electron beam
 - High beam current applications in Hall C
 - Low beam current applications in Hall B



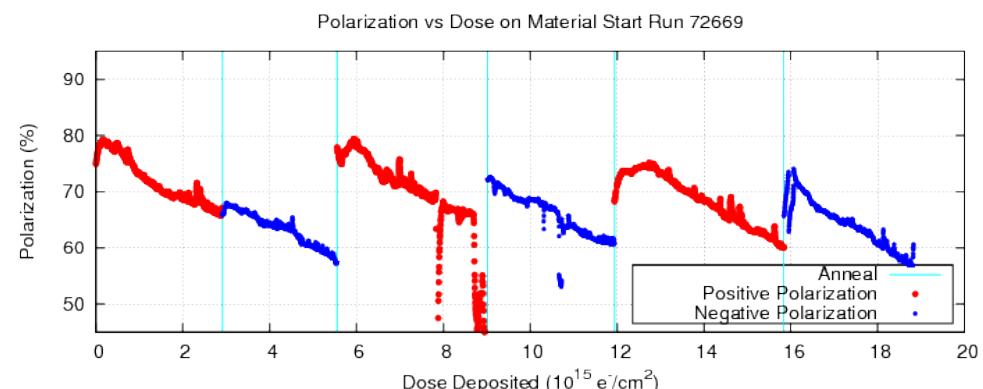
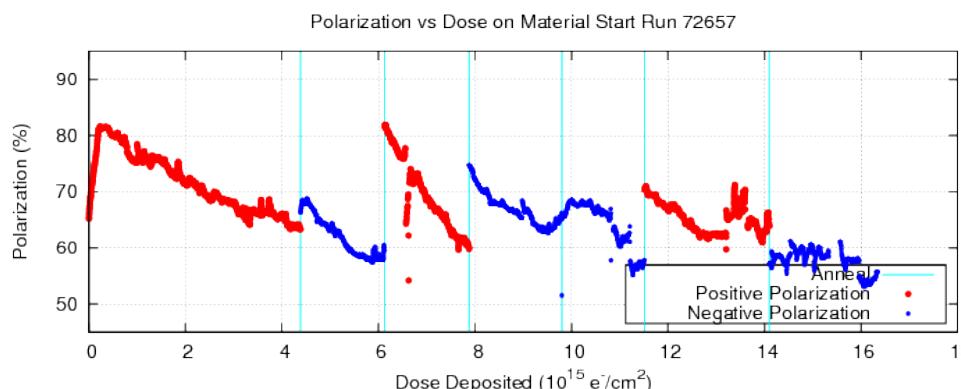
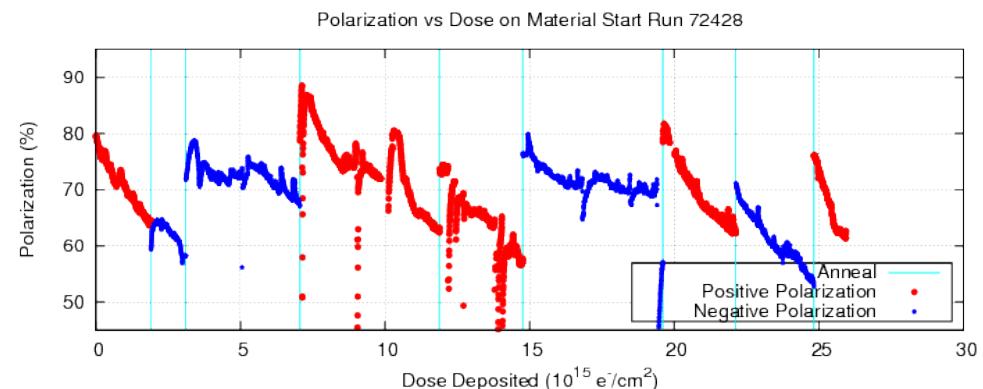
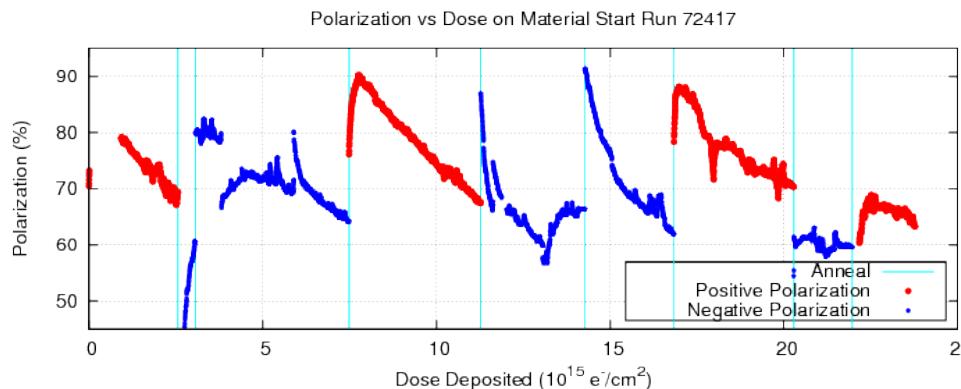
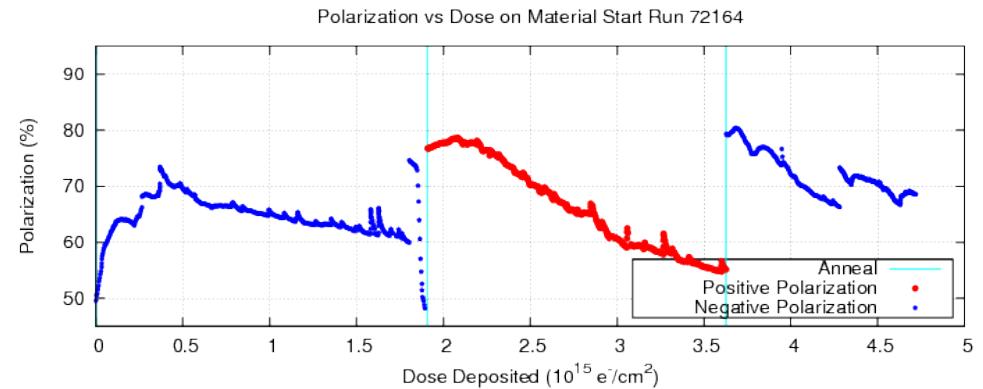
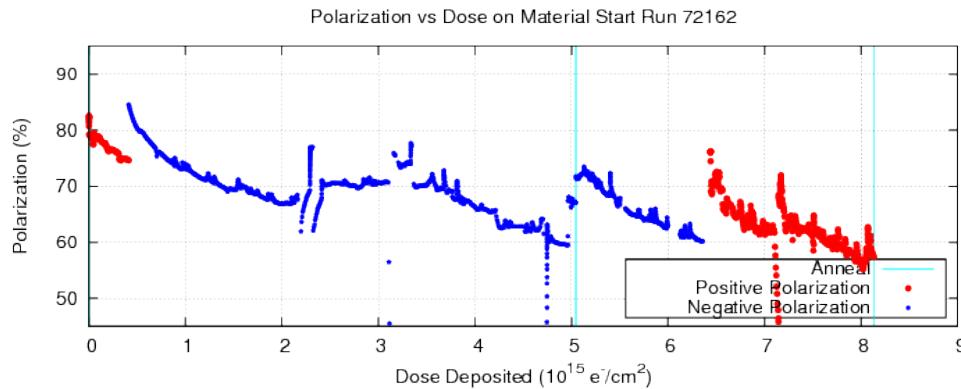
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Irradiations at MIRF



- Even irradiation throughout material is crucial
 - Target rotated to distribute charge
- Material inspected for tell-tale color change

More Material Lifetime Examples (Online Data)



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